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THE CHANGE IN FLOW PATTERN AMONGST OBSTACLES AT LOW WIND SPEEDS

C.J.M. AANENSEN

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SUMMARY OF
PORTON TECHNICAL PAPER NO. 328
DATE: 24 MAR 1953

THE CHANGE IN FLOW PATTERN AMONGST OBSTACLES AT LOW WIND SPEEDS

by

C.J.M. Aanensen

A wind tunnel study of the mean local wind (expressed as a fraction of the free air speed) about model buildings showed that a steady eddy pattern exists only at free air speeds of over 2 metres/second. As the free air speed is decreased progressively below this value the eddy pattern changes continuously until laminar flow over the greater part of the model is achieved.

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Introduction

In one of his reports on wind tunnel work Rouse (ref. 1) mentioned that a preliminary study of the wind flow around cubes had shown that at all wind speeds above 5 feet per second no change in flow pattern occurred with changing air-speed, but that at speeds below 3 or 4 feet per second a pronounced variation in eddy form took place. Aanensen (ref.2) also showed that the areas affected by gas in a model of Salisbury changed significantly when the wind speed in the tunnel fell below some value of the order of 1 - 2 metres/sec. The tunnel used for the Salisbury model work was not suitable for a quantitative investigation of this "critical" value of wind speed, so no further investigation of the change could be carried out at that time. It was, however, felt that some attempt should be made to ascertain whether or not the change in eddy pattern occurred with an irregular model such as that of a town at the same wind speed as that reported by Rouse for a regular array of cubes. It would also be of interest to obtain some indication of the suddenness of the onset of the change in pattern. To carry out this work it was necessary to transfer part of the Salisbury model to a smaller wind tunnel in which the wind speed could be finely controlled. Instead of relying on visible changes in the flow pattern as Rouse had done, or carrying out an analysis of gas affected areas as reported in P.T.P. 257, it was decided to use as indicator the ratio of the mean local wind at various positions about the model to the free air speed in the tunnel and then to supplement the knowledge thus obtained by such photographs of smoke movement as might be found useful.

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Experimental arrangements.

Two shielded hot wire anemometers of the type described by Simmons (ref. 3) were used for the investigation. These anemometers are very sensitive to low wind speeds, small in size, possess stable calibration, and because of the silica tubing are not of too short a time constant for the purpose in hand. They were mounted in a horizontal position at right angles to the axis of the tunnel and calibrated in this position for wind speeds from 0.15 m/sec. to 4.2 m/sec. The two hot wires were in series and fed by a common heater current of 0.56 amp. which was kept constant to 1 part in 1000. The horizontal position of the wires was chosen in spite of the knowledge that calibration at extremely low speeds would be more difficult because it was considered desirable to measure the winds at definite heights above the floor of the model. One of the anemometers was used to measure the undisturbed wind flow in the tunnel and for this purpose was placed at a height of 12 inches above the floor, whilst the other was used as a probe to measure the mean local wind at various positions about the model. In all cases the mean wind was obtained over a period of two minutes as an average of 30 individual readings (which was ample to define the mean air flow).

No attempt was made to measure wind directions in this work. The working section of the wind tunnel was 30 inches square in cross-section and 48 inches in length down wind. The portion of the Salisbury model (scale 1 : 120) used was 18 inches wide by 30 inches long, the average height of the model being 2.7 inches. Several orientations relative to the mean flow through the tunnel were utilised and measurements of the local wind were made at a number of positions.

Results.

Throughout the range of free air speed used (4 metres/second down to about 0.2 metres/second) it was found that the ratio of the mean local wind to the free air speed fell into two categories: above about 2 metres/second the ratio was constant for any chosen place of measurement, below this value of free air speed the ratio varied considerably. Two typical examples of measurements made are given herein, these having been chosen because they indicate two extremes of pattern. Each set consists of a series of measurements made in the vertical above a definite position, these positions being shown in the plans given in Fig. 1 and 3. The results (Figs. 2 and 4 respectively) show the variation of the ratio of the local speed to the free air speed with change in the latter for various heights of measurement. The range in heights extended from 0.75 inches to 6 inches, it being inconvenient to work at lower heights and unnecessary for the purpose in hand to go to greater heights. It will be seen that the local wind expressed as a fraction of the free air speed is constant for all free air speeds above a certain value. At lower speeds it changes rapidly with change in free air speed. In Fig. 2 it would appear that the region of constancy existed until the free air speed dropped below 1.5 m/sec. (The behaviour at a height of 4 inches appears somewhat anomalous but this is considered to be the effect of measurement at a position of an eddy pattern which in conforming

to the general change does not show it immediately as a change in its own ratio of speeds). At all heights the air speed ratio increased rapidly as the free air speed decreased and continued thus as far as the sensitivity of the anemometer allowed measurements to be made. In the case of the results portrayed in Fig. 4, the change from the steady state commenced at a free air speed of 2 metres/second, but below this speed the value of the ratio of wind speeds increases for the height of 3, 4 and 6 inches only, and for these levels the increase is only for a short range of free air speeds. Outside this range of wind and heights a decrease in the ratio of the winds takes place with decrease in the free air speed. (It should be noticed that for a short range of free air speeds, the local speed is greater than the free air speed, even though the height of the measurement is over twice the height of the model houses).

The differences between these two sets of results are considered to be entirely due to the change in location of the measurements and to the consequent differences in local eddy patterns formed at any particular free air speed. The important points arising from this investigation are that above a free air speed of about 2 metres/second the wind ratios are constant, that there is no unique "critical" value of the free air speed, and that below this speed the wind ratio shows a progressive change as the free air speed decreases. The region of constant wind ratio is interpreted to be that of constant eddy pattern and the qualitative results of previous investigations are confirmed.

Flow at low speeds.

An attempt was made to demonstrate visually the change in type of air flow by means of smoke. A drop of titanium tetrachloride was placed on a small perspex plate fitting flush with the floor of the model. At high air speeds it was obvious that the smoke was subject to rapid dispersal by turbulence. As the free air speed was decreased two effects were noticeable: (1) it was easier to see the smoke because of the decreased dilution, and (2) the turbulence became less as shown by progressively slower movements of the filaments of the smoke, which all the while became less torn and smoother. It was obvious that a transition to laminar flow was taking place. At very low speeds the plumes of smoke moved slowly and smoothly across the floor or up the sides of the model, the smoke thinning out slowly in the process. In an effort to record the type of flow, flash photographs were taken at various wind speeds (exposure approximately 0.005 sec.). In Fig. 5(a), (b), & (c) are three selected photographs showing the typical structure of the smoke plume for three wind speeds - 1.5 m/sec., 0.8 m/sec., and 0.4 m/sec. At 1.5 m/sec. the plume was quickly torn to shreds by the turbulence. At 0.8 m/sec. the smoke showed less violent turbulence and persisted for a greater distance close to the floor. (It should not be assumed that the plume lay permanently on the floor at this wind speed; it did so more often than not, but intermittently it was subject to relatively slow waving movements. At the lowest air speed the flow across the floor of the model was entirely laminar, the smoke eventually escaping up the walls of the model in smooth slowly waving filaments.

Since it appears that the breakdown in the steady eddy pattern which takes place at a free air speed of about 2 metres/sec. is associated with the gradual change to laminar flow, it is of interest to note the value of Reynold's Number at which it occurred. Taking the mean height (7 cm.) of a model building as a typical length, the Reynold's Number corresponding to 2 m/sec. is 9,000.

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2. Aanensen, C.J.M. P.T.P. 257. (1951).

3. Simmons, L.G.F., J.Sci. Inst. 26, 407. (1949).

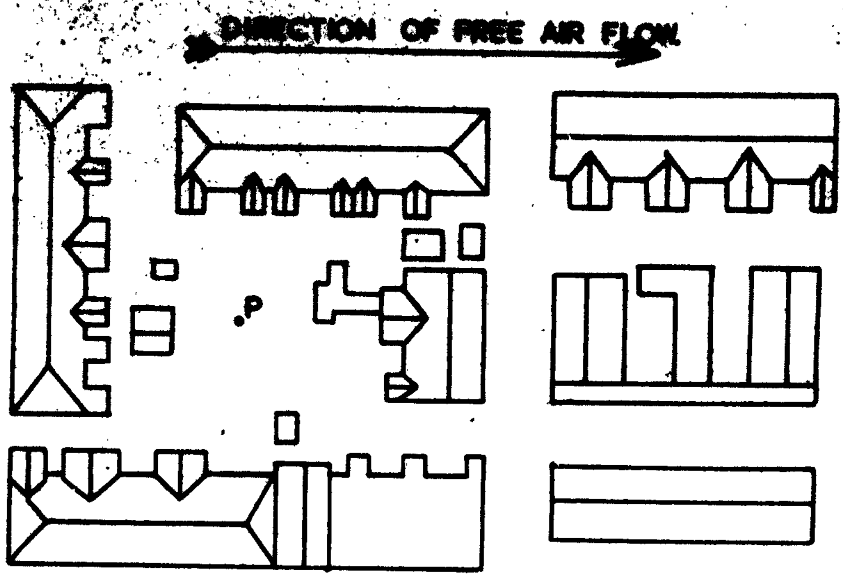

FIG. I. PLAN OF MODEL SHOWING POSITION (P) OF MEASUREMENTS OF FIG. 2

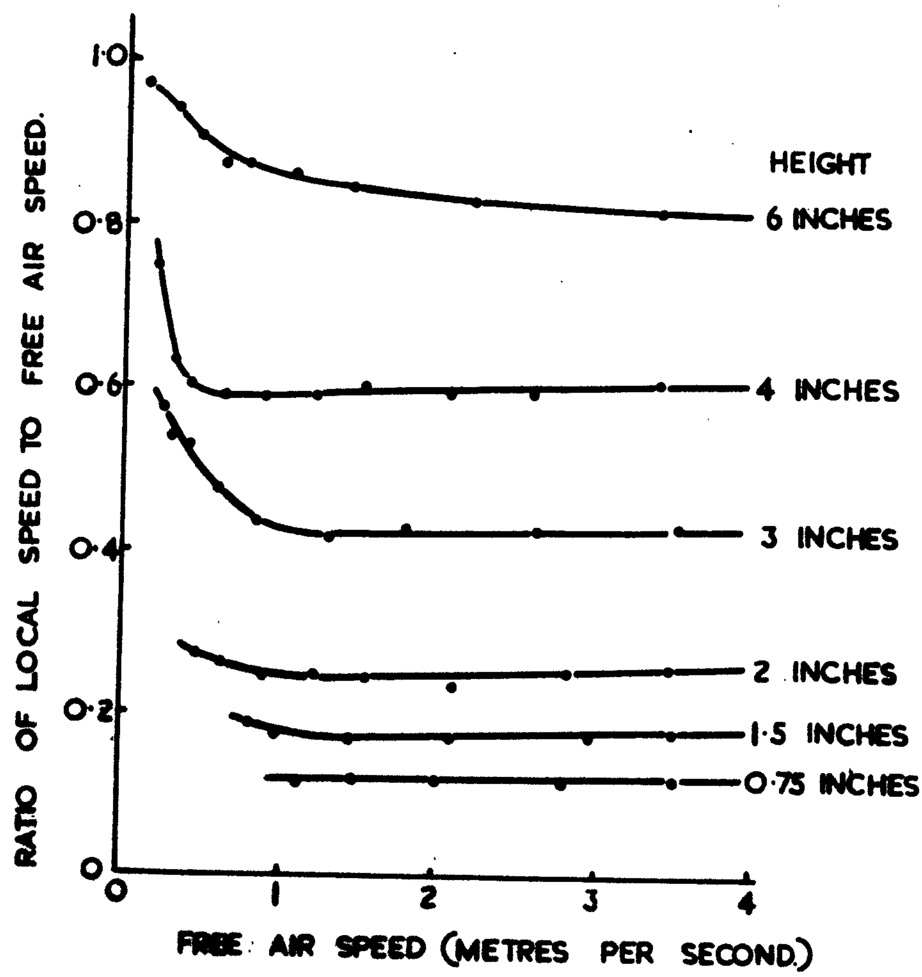

FIG. 2. RELATIVE WINDS AT POSITION SHOWN IN FIG. I.

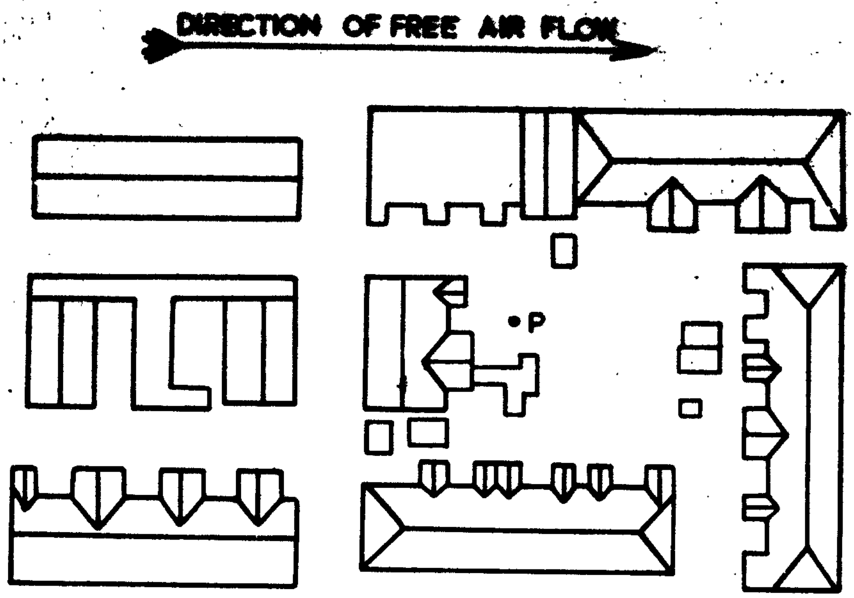

FIG. 3 PLAN OF MODEL SHOWING POSITION (P) OF MEASUREMENTS OF FIG. 4

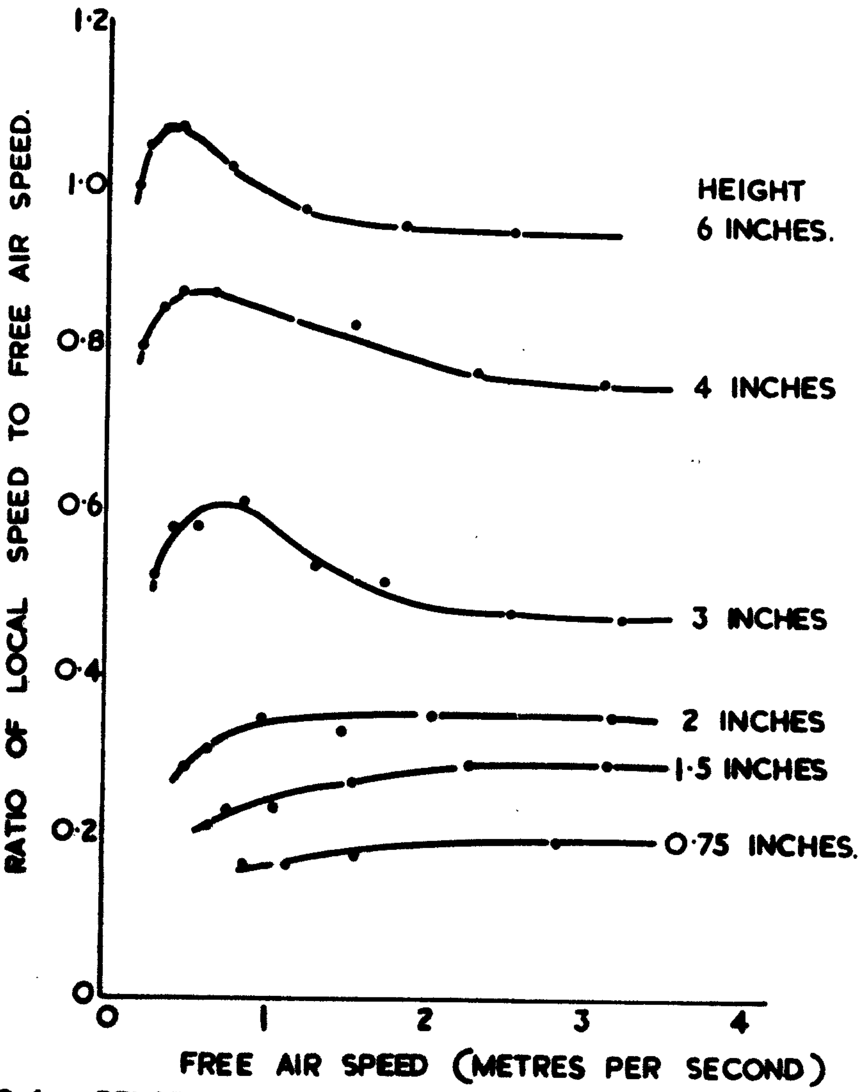

FIG. 4 RELATIVE WINDS AT POSITION SHOWN IN FIG. 3.

IC. 5.(a.) PHOTOGRAPH OF SMOKE PLUME WITH FREE AIR SPEED 1·5M/SEC. (AND DIRECTION LEFT TO RIGHT: THE SMOKE SHOWS A PERSISTENT EDDY BETWEEN THE HOUSES.)

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FIG. 5.(b.) SMOKE PLUME WITH FREE AIR SPEED 0·8 M/SEC. (AND DIRECTION LEFT TO RIGHT.)

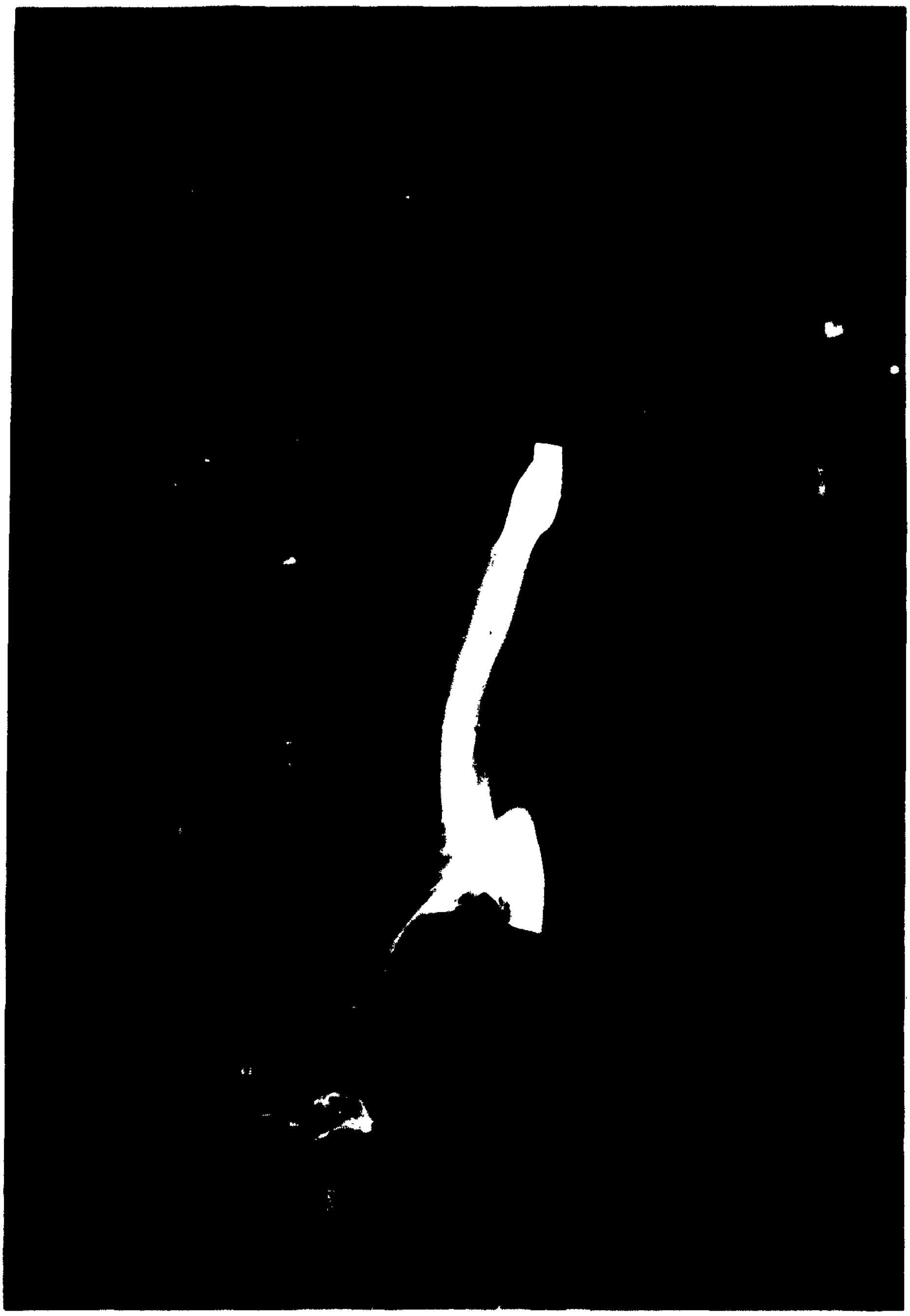

FIG.5.(C.). SMOKE PLUME WITH FREE AIR SPEED 0·4 M/SEC. (AND DIRECTION LEFT TO RIGHT.)

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